362

METEOROLOGICAL OFFICE
12 MAR 1971
LIBRARY

RESTRICTED CIRCULATION

This paper is not an official document: it is for information only and reference cannot be made to it in any printed publication without the permission of the author.

Occasional Note No. 34 (Agricultural Memo No. 362)

The "Oasis" Effect

0107252

General considerations

It is now increasingly appreciated that, in a given macro-meteorological situation, the rate of water-loss per unit area from a device such as a pan, a small pond, or from an isolated small area can, and generally does, differ systematically in varying degrees from the corresponding rate of loss of water from an extensive, homogeneous vegetated surface:- Such differences will tend to be least when water is freely available to the plant roots to meet the evaporative demand which the atmosphere is imposing on the plant.

It is possible to envisage a particular evaporating test surface, i.e. an evaporimeter, exposed to atmospheric influences in such a way that the rate of water loss per unit area would be less than that from the extensive area: however the more usual case is that in which the loss from the evaporimeter will lead to an overestimate of the loss from the extended area.

Such differences can be attributed to one or more causes e.g.

(i) differences in the mechanisms of turbulent exchange operating on the contrasting surfaces;

(ii) differences in the radiative and convective exchanges at the different surfaces;

(iii) differences between the vertical and horizontal gradients of temperature, vapour density and wind impinging upon the several surfaces.

Although all three causes contribute towards the observed results; the last, (iii), is the one on which attention is focussed in this note.

Consider an idealised, extreme situation viz that of a shallow tank of water placed in a hot arid desert.

(a) First, suppose that there is no horizontal air motion i.e. no wind.

The vapour pressure in the air immediately above the tank will initially be very low; that at the water surface will be the saturation vapour pressure corresponding to the temperature of the water surface. Water will be removed by molecular diffusion, the "cylinder" of air above the tank will be increasingly enriched with water vapour at the expense of the water in the tank. Sutton (1953 p. 303) deals with this case under certain boundary conditions: lateral diffusion of water-vapour is assumed to be negligibly small.

In practice, local convection currents will be present and transfer processes additional to molecular diffusion will be in operation.

/The

ORGS UKMO A
G. 13047/VT/2/71/150
National Meteorological Library
FitzRoy Road, Exeter, Devon. EX1 3PB

The rate of evaporation will be proportional to the current vapour pressure gradient. The drier the overlying air, the faster the rate of evaporation. If, as we postulate, the vapour is confined to the vertical "cylinder" of air then, as evaporation proceeds, the vapour pressure difference will decrease, and with it the rate of loss.

The rate of evaporation from the tank will bear little relationship to the rate of loss, if any, of water from the "desert" surface: indeed the inverse situation obtains, for the greater the rate of evaporation from the "desert" surface the higher the initial vapour pressure over the tank and the slower the evaporation from the tank.

(b) Now suppose there is a steady wind, then the vapour-enriched air above the tank will be continually removed and replaced by dry air; furthermore if the surface area of the tank is sufficiently small - say a few square feet - the original low value of the vapour density will be continually re-established and evaporation will take place at the initial rate for as long as there is water to be evaporated. Once again, the rate of loss of water from the tank, i.e. from the "evaporimeter", will bear no firm relationship to the rate of removal of water from the "desert" surface i.e. to the "evaporation" from the desert. (NB This is not to say that the rate of loss from various evaporimeters has no physical meaning nor practical significance in these circumstances). This situation arises, although less dramatically, in most parts of the world after a drought. Due to drought there may be little or no loss of water from the parched earth or wilted vegetation - but a great deal from any wet or continually dampened surface.

The discussion so far should clarify the distinction between actual evaporation (actual rate of loss of water from the suface exposed to atmospheric influences) and potential evaporation (the rate at which water would be lost from an extensive homogeneous surface - usually one of cropped grass is envisaged - the ground surface and/or plant roots having unhindered access to an unlimited supply of water).

We can, at this point, usefully refer to some ideas discussed by Chang (1968 pp 140 et seq). He follows Tanner (1957) who, when dealing with the effect of advected energy upon evapotranspiration, distinguishes between the "clothesline" and the "oasis" effects. The former arises at the leading edge of (say) an irrigated field bounded by dry area, and "may be considered negligible when the transformation of wind, temperature and humidity profiles from those of the upwind field to the vegetated surface is complete". It is basically this "leading edge" effect with which we are concerned in this paper. The "oasis effect" in Tanner's terminology is a "climatic characteristic since it affects the evapotranspiration rates many miles into an irrigated field". The characteristics of the air will not be closely coupled with the partitioning of net energy at ground level into that for heating the air and that for evaporation. Chang notes that "in some instances the oasis effect reflects the large scale upper air subsidence".

Quantitative analysis of some aspects of evaporation

A number of workers e.g. Pasquill (1943), Sutton (1953), Rider, Philips and Bradley (1963) have attacked the effect of wind at, and beyond, the boundary between two adjacent surfaces possessing different levels of surface wetness i.e. exhibit different vapour concentration.

/Our

Our starting point is Fig 1.

Let AB be the boundary (extending indefinitely in either direction) between a dry region to the left and a saturated surface to the right; and suppose pg be a strip of unit width. Following Sutton (1953 pp 304 et seq) let:

$u(m)$ = the mean speed of a uniform wind blowing perpendicular to AB:

x_o = the downwind distance from the boundary:

q_o = the vapour concentration in the air before it reaches AB

q_s = the vapour concentration at the evaporating surface

E = the <u>total</u> rate of evaporation per unit cross-wind width.

Consider a rectangular "box" of indefinite cross-wind length AB, of indefinite height AA' (= z), but of finite downwind extent (AD = BC = x_o).

Under steady conditions all the water vapour leaving the horizontal surface of the elementary strip pg will pass horizontally through the vertical strip gs. Sutton shows that, in these conditions and with a normal stability (adiabatic temperature lapse),

$$E = (q_s - q_o) . B u_{(m)}^{0.78} x_o^{0.89} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where B is a function of stability.

The effect of the progressive enrichment of the air-stream by the continued evaporation of the water vapour into it is expressed by the fact that the total rate of evaporation from strips such as pg does not grow proportionally to the downwind distance x_o, but at a slower rate. Panofsky (1958 p 203) illustrates the effect thus "..... evaporation depends upon the 8/9th power of the fetch. This means that, if the fetch is increased by a factor of 512 (2^9), the evaporation increases only 256 (2^8)-fold". In the limit (assuming that the stability and kinematic characteristics of the air-stream remain the same, that energy and water supply are available and sufficient to sustain the vapour concentration at the level q_s), Sutton notes that "if the wetted surface extends indefinitely downwind, a stage will be reached when the air over the surface is saturated and (local?) evaporation ceases".

Pasquill (1943), amongst others, has shown that the corresponding expression to Eq (1) for a wetted circular area is:-

$$E = (q_s - q_o) C u_{(m)}^{0.78} r^{1.88} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where r is the radius of the circle.

The average evaporation per unit area (which we will write E(av)) will be respectively:-

for the strip $\propto$ E(av)/area or E(av)/x i.e. $\propto x^{-0.11}$

for the circular area $\propto$ E(av)/area or E(av)/r^2 i.e. $\propto x^{-0.12}$

/The

The change in evaporation rate averaged over the whole area (i.e. on a per unit area basis) with increasing downwind distance from the leading point of the disc, for r = 10 cm n = 1 to 7 can be appreciated from the following figures:-

n =	1	2	3	4	5	6	7
(metres)	0.1	1	10^1	10^2	10^3	10^4	10^5
$\frac{E_{av}}{r^2}$ $\propto$	7.57	5.75	4.37	3.31	2.51	1.90	1.45

An idea of the way in which additional increments of evaporating area (corresponding to increments of $\underline{x}$ in Fig 1, and increments of $\underline{r}$ for the disc) contribute to the evaporation, is indicated by the trend of the series below in which the figures are proportional to the additional evaporation averaged over the additional area.

(i)	x(cms)	$10-10^2$	10^2-10^3	10^3-10^4	10^4-10^5	10^5-10^6	10^6-10^7
	Increment of E(av) prop. to	0.59	0.45	0.35	0.27	0.22	0.16
(ii)	r(cms)						
	Increment of E(av) prop. to	0.57	0.43	0.33	0.25	0.19	0.14

Some practical implications and evidence from field-work

The possibility of using the formula discussed above to compute the water loss over an extended area from that lost from a small evaporimeter has been discussed by e.g. Green (1958, 1960) who sought a "correction factor" to compensate for the "oasis effect". He suggests that beyond a radius of about 200 yds (1.82×10^4 cm or 182 metres) the rate of decrease of average evaporation changes only slowly and one may therefore postulate that such an area represents the idealised indefinitely large wetted area associated with the concept of potential transpiration. On this assumption he finds that

$$\frac{\text{evaporation rate per unit area for r = 11 inch}}{\text{" " " " " " r = 200 yds}} \sim 2.2$$

Our independent computation gives 6.6/3.1 ~ 2.1. Had we assumed the "infinitely large" area to be defined by $r = 2 \times 10^5$ cms (a ten-fold increase), the ratio becomes 2.75.

Direct field measurements of the horizontal gradient of the actual evaporation from the leading edge are few, but we may quote Rider et al (1963 p 259) for some derived estimates of evaporation as an air-stream moves from a (dry) tarmac surface into an irrigated grassed area. They postulate that the true evaporation rate per unit area E (say) is that required exactly to absorb all the net radiant energy impinging on the suface at a distance of (x =) 1600 cms from the leading edge. If E(o - x), where x is successively 100, 400, 1600 cms, are the evaporation rates per unit area from strips of increasing downwind fetch of 100, 400, 1600 cms, then -

/E(0 - 100)

E(0 - 100): E(0 - 400): E(0 - 1600): E: = 3.7: 2.5: 1.7: 1

and hence E(0 - 100): E(0 - 400): E(0 - 1600): = 2.2: 1.5: 1

The corresponding ratios based upon Eq 1 are 2.0: 1.2: 1. Millar (1964) from Australia reports losses from lysimeters placed downwind from the leading edge of a small irrigated field adjoining a drier area: a graph in his paper indicates local evaporation rates (mm/hr) averaged over about 8 hours in a single day of:-

Distance from leading edge (cm)	14	167	472	1387
Evaporation rate mm/hr	0.78	0.74	0.70	0.70

i.e. a much less striking contrast than that obtained by Rider et al. Halstead and Covey (1957) computed evaporation rates for moist areas of increasing dimension situated in an otherwise completely dry area. Rather extreme initial conditions were postulated giving:-

6 ft tank	0.45 cm/hr
50 ft plot	0.26 "
300 ft "	0.19 "
1 mile field	0.13 "

Chang (ibid p 141) concludes from these results that the "clothesline" effect extends more than 300 ft into the field.

In his discussion of the subject Chang (ibid) notes research findings to the effect that the "clothesline" effect, even in humid region, can extend to a distance of 40 times the crop height, and that an upwind "guard-ring" of 50 m is necessary to minimise the effect in humid climates; whilst in desert areas even a distance of 400 metres would not be too large. Turning to the "oasis effect" proper, he states that this is often measurable many miles into an irrigated field in an arid climate.

In Texas; Lemon, Glaser and Satterwhite (1957) report the "oasis effect" at a distance of 10 miles into an irrigated cotton field - the evaporation rate was 1.65 times that attributable to the net radiation for a 24-hour period. In a more humid climate the effect is not so great; Graham and King (1961) in Ontario found that when the local surroundings of their irrigated corn were dry, the ratio between evapotranspiration and net radiation was 20 per cent higher than when the surroundings were moist.

Other research papers dealing in particular, with the "clothesline" effect are Davenport and Hudson (1967 (a)(b)).

Concluding Comment

The complications inherent in measuring the general evaporation (i.e. that from extended areas) from the water loss from evaporimeters will now be obvious.

/Perhaps

Perhaps less immediately obvious is that in field investigations in which water vapour (and indeed most other meteorological elements) are involved, the interference of conditions in any given plot by the activity in adjacent plots can seriously vitiate conclusions. In particular such difficulties are likely to arise when randomised layouts give rise to adjacent small plots bearing crops of different geometrical characteristics (height, density etc).

R W GLOYNE

Meteorological Office
Edinburgh

January 1971

G. 13047/VT/2/71/150

REFERENCES

Chang J H (1968) — Climate and Agriculture. Aldine Pub Co, Chicago. pp 304.

Davenport D C, Hudson J P (1967 (a)) — "Changes in evaporation rates along a 17-km transect in the Sudan Gezira" Agr Meteorol 4(1967) pp 339-352 Elsevier Press, Amsterdam.

Davenport D C, Hudson J P (1967 (b)) — "Meteorological observations and Penman estimates along a 17-km transect in the Sudan Gezira" Agr Meteorol 4 (1967) pp 405-414 Elsevier Press, Amsterdam.

Graham W G, King K M (1961) — "Fraction of net radiation utilised in evapo-transpiration from a corn crop" Proc Soil Sc Soc of Am 25 pp 158-160.

Green F H W (1958) — "Problems raised by the operation of, and the results from, a small network of British Evaporation Measuring Stations" Comptes Rendus et Rapports: Ass General IUGG Toronto 1957 Gentbrugge 1958 III pp 444-451.

Green F H W (1960) — "A technique for measuring potential evaporation and some of its applications". London "Water and Water Engineering" Dec 1960 pp 3-8.

Halstead M H, Covey W (1957) — "Some meteorological aspects of evapo-transpiration" Proc Soil Sc Soc of America 21 p 461-464.

Lemon E A, Glaser A H, Satterwhite L E (1957) — "Some aspects of the relationship of soil, plant and meteorological factors to evapo-transpiration" Proc Soil Sc Soc of Am 21 pp 464-468.

Millar B D (1964) — "Effect of local advection on evaporation rate and plant water status" Austr J Agr Res 15 pp. 85-90.

Panofsky (1958) — "Introduction to Dynamic Meteorology" Penn State University pp. 243.

Pasquill F (1943) — "Evaporation from a plane, free liquid surface into a turbulent air stream" London Proc Roy Soc Ser A 182 No A988 Sept 43 pp. 75-95.

/Rider N,

Rider N, Philip J R, Bradley E F (1963) "The horizontal transport of heat and moisture - a micrometeorological study" London Quart J Roy Met Soc 89 No 382 pp. 507-531.

Sutton O G (1953) "Micrometeorology" London McGraw Hill pp. 333.

Tanner C B (1957) "Factors affecting evaporation from plants and soils" Journal of Soil Water Conservation 12:

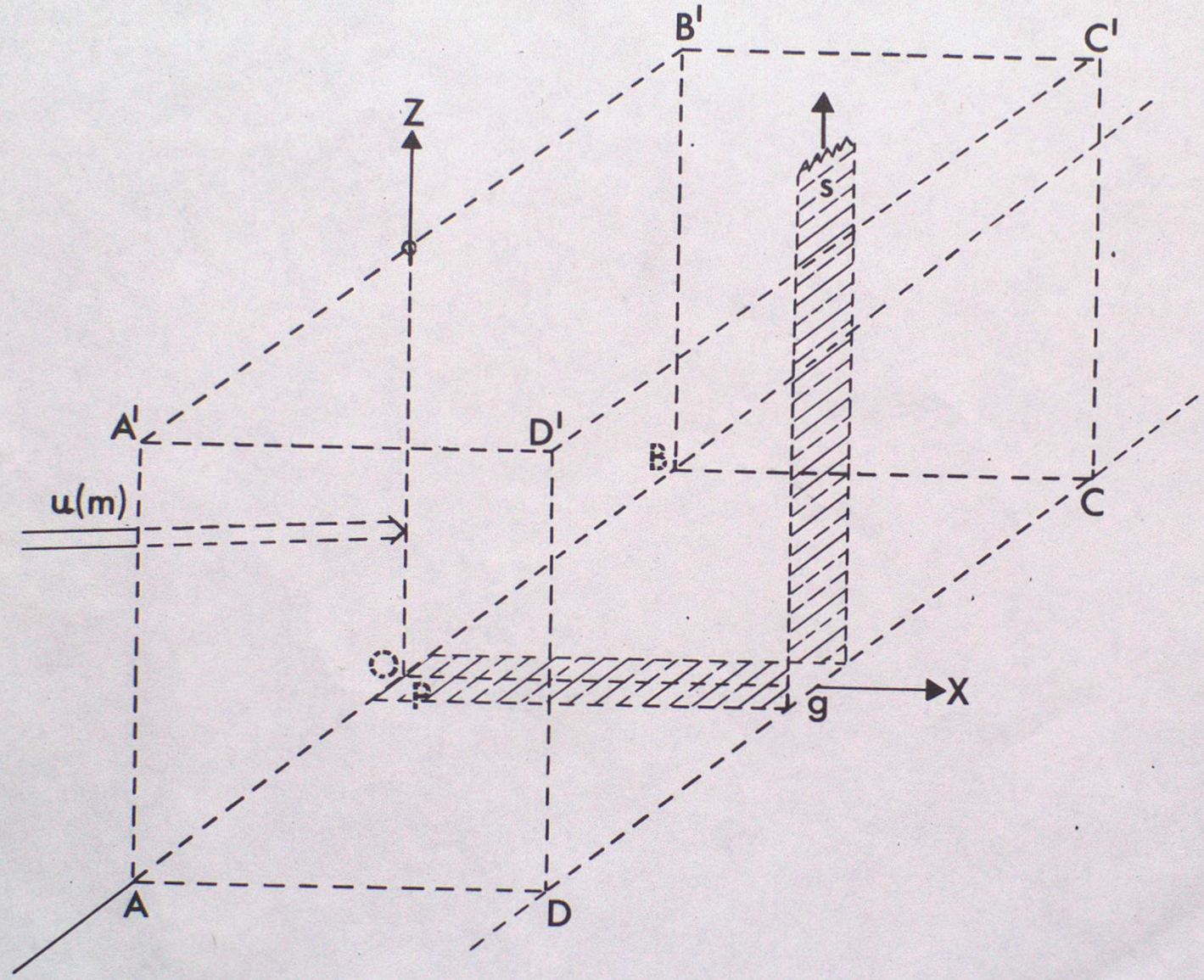

Fig. 1 Co-ordinate system for computation of evaporation from strip pg, surface vapour density q_s into a steady mean wind u(m) having vapour density q_o
For additional information, see text p. 4